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# Climate Change Impact on Pakistan's Water Quality and Biodiversity: Its Management and Future Policies

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## ABSTRACT

Pakistan is particularly susceptible to the negative consequences of climate change, which seriously jeopardize its abundant biodiversity and water security. This narrative review summarizes the most recent research on how changing climate patterns, such as rising temperatures, unpredictable precipitation, and an increase in the frequency of extreme events, are making water scarcity worse and lowering water quality through pollution, salinization, and changed hydrological regimes. The loss of biodiversity in both aquatic and terrestrial ecosystems is a result of these changes, endangering endemic species as well as vital habitats like the northern glaciers and the Indus Delta. The review critically examines recent national policies (2020–2025), including the Protected Areas Initiative and the Recharge Pakistan initiative, and provides an overview of current management practices. It comes to the conclusion that Pakistan's resilience and sustainable development objectives will be seriously jeopardized in the absence of integrated, cross-sectoral policies that clearly connect biodiversity conservation and water resource management. The article concludes with tactical suggestions for improving institutional capacity, promoting regional cooperation, and improving climate adaptation.

## INTRODUCTION

One of the most difficult problems of the twenty-first century is the global climate crisis, which is caused by human-caused greenhouse gas emissions. It has significant and repercussions for human health, environmental stability, and socioeconomic advancement (1). Despite being a global phenomenon, its effects are not equally distributed; developing countries, especially those with agrarian economies and little capacity for adaptation, are disproportionately affected. This climate injustice is best exemplified by Pakistan. Even though it contributes less than 1% of the world's greenhouse gas emissions, the Global Climate Risk Index (2) clearly shows that it is among the top ten nation's most at risk from climate change. Because of its distinct and complicated topography, which includes the high-altitude glaciers of the Hindu Kush, Karakoram, and Himalayan ranges, the deltaic plains of the Indus River, and the arid regions of Balochistan, the country's ecosystems and water resources are particularly vulnerable to changes in the climate. A perfect storm of vulnerability is created by this geophysical setting, high population density, and economic reliance on climate-sensitive industries like agriculture.

Under climate stress, the complex and interconnected relationship between biodiversity and water resources forms a crucial nexus. Pakistan's economy and ecology depend heavily on water to support its industrial operations, domestic needs, and agricultural output. It also supports a diverse range of species in its rivers, wetlands, forests, and rangelands (3). The hydrological cycle is directly disrupted by climate-induced stressors like changed precipitation patterns, faster glacial melt, and an increase in the frequency of extreme heat events and flooding. Through processes like salinity intrusion, concentrated pollutant loads, and elevated water temperatures, this disruption shows up as a serious crisis of water quality in addition to a crisis of water quantity, such as scarcity and floods (4). The loss of biodiversity is primarily caused by the deterioration of water quality, which also contaminates aquatic habitats, changes the species composition, and fragments ecosystems. This creates a vicious cycle of ecological decline that threatens the very ecosystem services that sustain human resilience (5).

Therefore, the goal of this narrative review is to present a thorough and integrated analysis of the predicted and observed effects of climate change on Pakistan's water quality and the ensuing impacts on biodiversity. It goes beyond a compartmentalized analysis to clearly explain the important connections between these two fields, contending that they cannot be studied separately. Additionally, from 2020 to 2025, the review critically evaluates the effectiveness of current management practices and the changing policy landscape, highlighting both promising initiatives and enduring implementation gaps. Through the integration of scientific evidence and policy analysis, this article seeks to steer Pakistan toward a more resilient and sustainable future by presenting strategic recommendations that prioritize inclusive adaptation, technological innovation, and integrated governance.

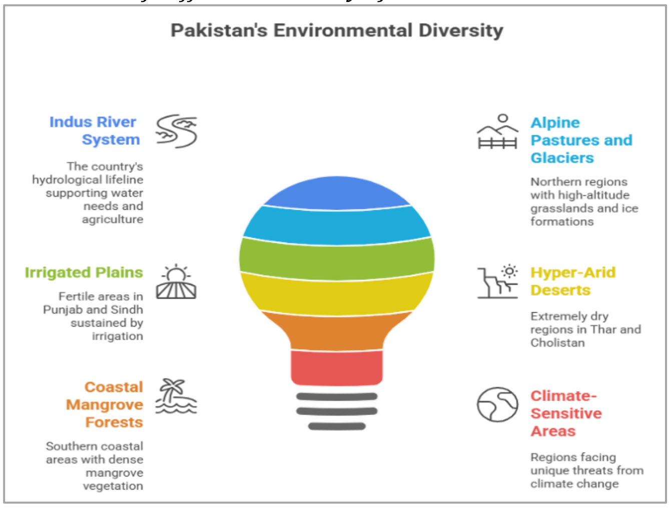
## OVERVIEW OF CLIMATE CHANGE IN PAKISTAN

### Geographic, Climatic, and Hydrological Setting

Although Pakistan has a primarily arid to semi-arid climate, its environmental diversity and vulnerability are supported by striking spatial heterogeneity. The Indus River System, a vast network of rivers primarily fed by seasonal monsoon rains and, crucially, meltwater from the second-largest volume of glaciers outside the polar regions, located in the Hindu Kush-Karakoram-Himalayan ranges, dominates the country's hydrology (6). This system serves as the country's arterial lifeline, providing the majority of its drinking and industrial water needs as well as more than 90% of its agricultural output, which employs almost half of the workforce. In the north, the alpine pastures and frozen, high-altitude glaciers give way to the heavily irrigated plains of Punjab and Sindh, which subsequently merge into the salty, hyper-arid deserts of Thar and Cholistan, and in the south, the fertile but endangered coastal mangrove forests and deltaic ecosystem of the Indus Delta (7). This geographical gradient produces a patchwork of separate but linked climate-sensitive areas, each of which is threatened differently by a changing climate.

**Figure 1**

*illustration of Different Diversity of Pakistan*

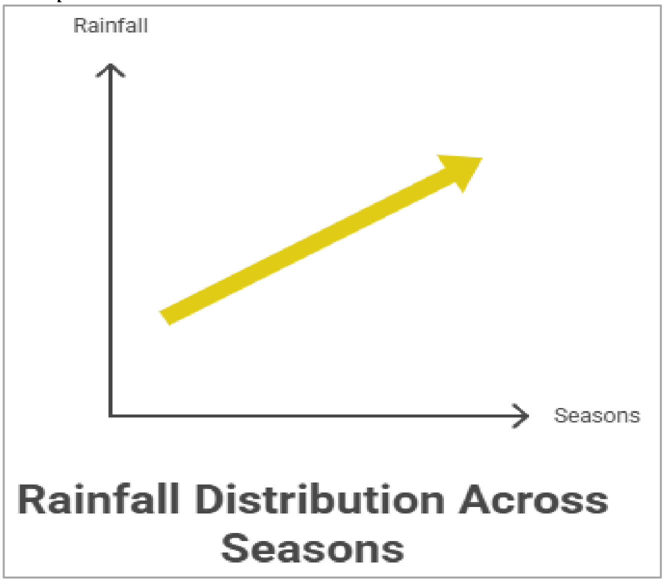



### Observed Trends and Future Projections

Recent decades' worth of empirical climate data show clear and concerning trends for Pakistan. The nation's mean annual temperatures are steadily rising, indicating a warming rate that is much faster than the global average. Glacier melt is directly accelerated by this warming, which is not uniform and is higher in the northern highlands. A decrease in total winter rainfall (which impacts the Rabi crop season) and an increase in the intensity and variability of the summer monsoon (which increases the likelihood of cloudbursts and catastrophic floods) are two examples of the increasingly irregular and unpredictable precipitation patterns (6), (8). Several climate-related disasters have occurred since 2020, most notably the 2022 super-floods that flooded a third of the nation and showed the new scope of climate-induced disasters. Concerning climate projections for the next few decades indicate that mean and extreme temperatures will continue to rise, the hydrological cycle will become more intense with more variable rainfall, and glaciers will retreat more quickly and nonlinearly (7). A long-term existential threat to water security will result from this, as the Indus Basin is likely to experience a "peak water" scenario, in which river flows first rise as a result of meltwater before going into a phase of permanent decline.

**Figure 2**

*Precipitation Patterns in Pakistan*

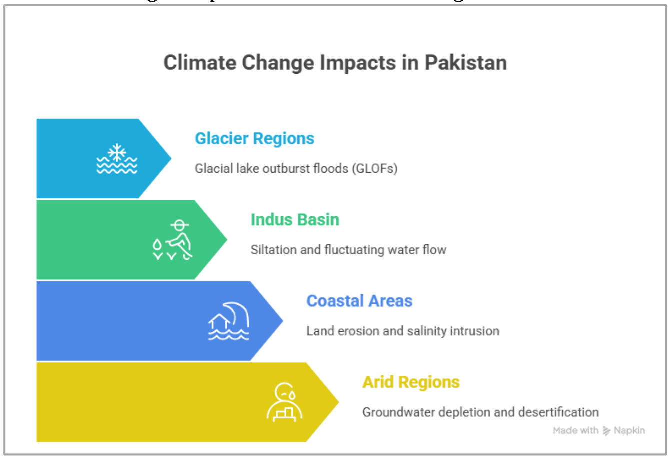



### Climate-Sensitive Regions

Several important regions are particularly affected by these climate changes. The nation's agricultural heartland, the Indus Basin, is under tremendous strain from siltation, fluctuating flow, and deteriorating water quality. Rapid sea level rise is causing land erosion and disastrous salinity intrusion into freshwater aquifers and agricultural land in coastal areas, especially the Indus Delta. This process is made worse by decreased Indus River flows. In addition to glacial retreat, the northern glacier-fed regions are experiencing a higher risk of Glacial Lake Outburst Floods (GLOFs), which directly endanger infrastructure and communities downstream. In the meantime, traditional livelihoods are being pushed to the limit in the arid and semi-arid regions of Thar and Balochistan due to severe groundwater depletion, desertification, and worsening droughts. Designing focused and successful adaptation strategies requires an understanding of the unique vulnerabilities of these areas (9).

**Figure 3**

*Climate Change Impacts on Pakistan's Regions*




## IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

### Hydrological Disruptions

Water allocation plans and agricultural calendars are being disrupted by seasonal flow variability and altered precipitation patterns. Pakistan is particularly vulnerable to changes in the cryosphere because of its reliance on the Indus River. River flows are temporarily increasing due to accelerated glacial melting, but this "glacial subsidy" is unsustainable and obscures the imminence of a serious water shortage when these natural reservoirs are exhausted (8). Devastating floods and more severe droughts are caused by this phenomenon, which exacerbates the hydrological extremes.

### Groundwater and Regional Case Studies

Another crucial problem is the disparity between groundwater recharge and extraction. Particularly in Punjab and Balochistan, intense irrigation and a shortage of surface water during droughts have caused significant groundwater depletion. Regional case studies illustrate a variety of issues, such as the siltation and flow variability in the Indus Basin, the aquifer drawdown and persistent drought in Balochistan, and the severe erosion and seawater intrusion in the Sindh delta brought on by the Indus's diminished freshwater flows (9).

## CLIMATE CHANGE AND WATER QUALITY DEGRADATION

### Mechanisms of Degradation

Because rising temperatures increase the toxicity of pollutants, accelerate chemical reaction rates, and lower dissolved oxygen levels in freshwater bodies, they have a direct impact on water chemistry (10). Aquifers in coastal regions are experiencing widespread salinity intrusion due to sea level rise and decreased river discharge, making the water unfit for irrigation and drinking. In the Indus Delta region, this is especially severe (11).

### Pollution and Health Impacts

Existing pollution pressures are made more dangerous by climate change. Higher nutrient loading (nitrogen, phosphorus) in water bodies can result from intensified agricultural runoff caused by warmer temperatures and fluctuating flows, which encourages eutrophication and algal blooms (12). This raises the possibility of microbial contamination when combined with insufficient wastewater treatment. Together, these elements increase the risk of public health issues, such as cholera and typhoid outbreaks, particularly following floods (13).

## EFFECTS OF CLIMATE CHANGE ON BIODIVERSITY

### Overview and Aquatic Impacts

Throughout its six main ecological zones, Pakistan is home to a substantial amount of biodiversity. These ecosystems are changing quickly as a result of climate change. Fish migration and spawning patterns in aquatic environments are being impacted by changing flow regimes and rising water temperatures, endangering endemic species like the Mahseer. Changes in water quality and habitat destruction pose a serious threat to aquatic invertebrates and amphibians (14).

### Terrestrial Impacts and Case Studies

The biodiversity of the land is also in danger. Plant-pollinator synchronization is being upset by phenological changes, and species are being forced to relocate their ranges often with little success due to habitat loss and fragmentation. The loss of essential wetlands, which are critical stops for migratory birds on the Central Asian Flyway, the rapid decline of mangrove forests in the delta as a result of decreased freshwater and silt flows, and the critically endangered Indus River Dolphin, whose habitat is fragmented by barrages and degraded by pollution, are all examples of iconic case studies (15).

## INTERLINKAGE BETWEEN WATER QUALITY AND BIODIVERSITY: A SYNERGISTIC CRISIS

### Water Ecosystems as Biodiversity Hotspots and the Chemistry of Life

Despite making up less than 1% of the Earth's surface, freshwater ecosystems such as rivers, lakes, wetlands, and estuaries are home to over 10% of all known species, making them disproportionately important hotspots for biodiversity (16). These systems, which range from the mangrove-ringed creeks of the Indus Delta to the glacially-fed streams of the north, are the main drivers of ecological productivity in Pakistan. These ecosystems' ability to survive depends not only on the amount of water present but also on the quality of that water. A particular "chemical habitat" is created by variables like temperature, dissolved oxygen, pH, salinity, and nutrient concentrations, and it determines a species' ability to survive, reproduce, and disperse (17). For example, high turbidity and pollutant loads negatively affect the acoustic environment and availability of prey for the Indus River Dolphin, a functionally blind cetacean that uses echolocation for navigation and hunting (18). Similar to this, the delta's mangrove ecosystems, which act as nurseries for marine fish, are collapsing in associated fish and invertebrate populations as a result of stunted growth and die-offs brought on by rising water salinity and the buildup of heavy metals from industrial effluent (19).

### The Vicious Cycle: How Poor Water Quality Undermines Ecological Balance

A series of detrimental consequences that upset ecological balance are brought on by the deterioration of water quality. Increased nitrogen and phosphorus loads from agricultural runoff cause eutrophication, which in turn causes algal blooms that, when they break down, reduce dissolved oxygen, resulting in hypoxic "dead zones" that suffocate fish and benthic invertebrates (20). By removing sensitive species one at a time, this process streamlines food webs and lowers the resilience of entire ecosystems. Climate change also multiplies the threat. The stress on aquatic life is exacerbated by rising water temperatures, which also decrease the water's ability to carry oxygen and make some pollutants, like ammonia, more toxic (21). According to a 2025 study on the Ravi River, the combination of high temperatures and industrial ammonia pollution caused 90% of native fish species that were tested to die during heatwaves, a situation that is expected to occur more frequently. Climate change deteriorates water quality, which lowers biodiversity, which lowers the ecosystem's ability to provide essential services like flood attenuation, nutrient cycling, and water filtration services that are essential for climate adaptation and human well-being (22). This leads to a vicious, self-reinforcing cycle.

### Innovative Frameworks and the Path Forward

A paradigm change from compartmentalized management to integrated, predictive frameworks is necessary to address this synergistic crisis. The complex, cumulative stressors of the Anthropocene cannot be adequately addressed by the conventional method of establishing stand-alone water quality standards for individual pollutants. Using "Environmental DNA (eDNA) Biomonitoring" in conjunction with "Ecological Thresholds Analysis" is a novel strategy. Authorities can perform quick, thorough biodiversity audits to identify ecosystem stress long before fish kills or other obvious crises happen by collecting water samples for genetic material released by organisms (23). This information can be used to identify physical and chemical thresholds unique to an ecosystem that, when exceeded, result in a predictable decline in biodiversity. In order to facilitate proactive reservoir water release to cool and clear the river during heatwaves, a 2025 pilot project in the Hunza River, for instance, set a threshold of 25°C and a particular turbidity level beyond which Snow Trout populations sharply decline (24). By clearly connecting water quality metrics to biodiversity outcomes and guaranteeing that water governance becomes synonymous with ecosystem governance, this shifts management from a reactive to a proactive approach.

## MANAGEMENT STRATEGIES AND ADAPTATION MEASURES

### Sustainable Water Management and Conservation Technologies

Although their adoption is still dispersed, a variety of sustainable water management and conservation technologies are being promoted in response to the growing water stress. There is a strong push to switch from traditional flood irrigation to high-efficiency systems like drip and sprinkler irrigation, which can reduce water use by 30–60% while maintaining yields, at the agricultural level, which uses more than 90% of Pakistan's water (25). Similarly, to guarantee uniform water distribution and reduce waste, laser land leveling of fields is being promoted. Generally speaking, one of the most important aspects of national water policy is the modernization of canal infrastructure, which includes lining watercourses to stop seepage losses. Enhancing water productivity in a warming climate requires not only supply-side management but also demand management through the development of drought-resistant crop varieties and the cultivation of less water-intensive crops (such as switching from sugarcane to millets or pulses) (26).

### Ecosystem-based Adaptation (EbA) and Nature-based Solutions (NbS)

Ecosystem-based adaptation (EbA) and nature-based solutions (NbS) are being promoted as a result of the growing realization that engineered solutions by themselves are inadequate. These methods increase resilience and offer several co-benefits by utilizing natural processes. An excellent example is the flagship "Recharge Pakistan" project, which aims to restore degraded ecosystems, replenish aquifers, and lower flood peaks downstream by strategically using existing wetlands, floodplains, and depressions to capture and store seasonal floodwaters (21). Large-scale afforestation and reforestation initiatives, like the "10 Billion Tree Tsunami," also seek to sequester carbon, stabilize soils, and control water cycles. Initiatives to restore mangroves and reintroduce freshwater flows are essential NbS for preventing salinity intrusion, safeguarding coastlines from storm surges, and maintaining vital fish breeding grounds in the Indus Delta (27). When compared to grey infrastructure, these methods are frequently more economical and long-lasting.

### Technological Innovations and Community-Based Management

Strong tools for climate adaptation are provided by the digital revolution. In order to track changes in glacier extent, soil moisture, crop health, and water quality in real time, remote sensing and Geographic Information Systems (GIS) are being used. Satellite data is used by initiatives such as the International Water Management Institute's (IWMI) "Water Productivity Atlas" to give farmers and decision-makers useful information about water use efficiency. Improving flood and drought early warning systems requires the installation of automated weather stations and river flow sensors. In order to guarantee local ownership and sustainability, community-based resource management is essential in addition to these technological advancements. This entails creating community-led associations of water users to ensure fair distribution, encouraging watershed management by means of local forest and rangeland stewardship, and launching awareness campaigns to encourage water-saving behaviors at the household level (28). In the end, local communities' acceptance and integration of any technological or policy intervention determines its success.

### Role of Academia and Research Institutions

The Global Change Impact Studies Centre (GCISC), the Pakistan Council of Research in Water Resources (PCRWR), and other universities are among the academic and research organizations in Pakistan that are becoming more and more important to the ecosystem that builds resilience. From salt-tolerant crop varieties to inexpensive water purification systems, their work is essential in creating context-specific adaptation technologies, evaluating sectoral impacts, and producing localized climate projections (29). Additionally, they are vital centers for capacity building, educating the upcoming generation of environmental policymakers, water specialists, and climate scientists. For management strategies to be evidence-based, creative, and suited to Pakistan's particular socio-ecological context, it is imperative that the connections between research, policy, and practice be strengthened.

## POLICY FRAMEWORK AND INSTITUTIONAL RESPONSE (2020–2025 UPDATES)

### National Policy Developments

There has been a lot of policy activity between 2020 and 2025. As a component of the "Green Stimulus," the Protected Areas Initiative (2020) seeks to enhance and broaden protected area management in order to preserve biodiversity (30). A concentrated attempt at groundwater sustainability can be seen in Balochistan's Integrated Water Resources Management Policy (2024). An important project aimed at restoring ecosystems for flood control and water security is "Recharge Pakistan" (31).

### International Partnerships and Institutional Roles

International cooperation is essential. Restoring the ecological health of the Indus Basin is the goal of the "Living Indus Initiative," which was named a UN World Restoration Flagship in 2024 (27). IWMI/CGIAR research and partnerships such as the Australia-Pakistan Water Security Initiative (APWASI) are offering digital tools and technical assistance for water management. Better governance and fund mobilization are being achieved institutionally with the creation of the Pakistan Climate Change Authority and a Climate Finance Wing (7).

### Implementation Challenges

Even with these developments, there are still many obstacles to overcome. Conflicting goals result from the fragmentation of policies in the environmental, agricultural, and water sectors. Lack of high-resolution data for evidence-based planning, lax enforcement of regulations, and a lack of funding are examples of persistent problems. To close the gap between the intention of policies and their practical implementation, there is an urgent need for increased capacity building and inclusive stakeholder engagement.

## FUTURE DIRECTIONS AND RECOMMENDATIONS: AN INTEGRATED ROADMAP FOR RESILIENCE

### Policy and Governance Innovation

The incorporation of Climate-Biodiversity-Water (CBW) Impact Assessments into national sectoral policies and major development projects, especially in the areas of industry, urban planning, and agriculture, is the most important future direction. This would go beyond the current, frequently cursory environmental impact assessments and legally require projects to show no net loss or gain to water quality and critical biodiversity (32). In addition, the emerging idea of "Water-Quality Trading Markets," which was influenced by carbon markets, ought to be tested in industrial areas. This would provide a financial incentive for cross-sectoral pollution reduction by enabling a factory that exceeds its pollution cap to buy credits from a farmer who has decreased agricultural runoff through sustainable practices (33).

### Technological and Data-Driven Solutions

Pakistan's major river basins require a leap into the "Digital Water Twins" era. In order to simulate the effects of different climate and management scenarios not only on water quantity but also explicitly on water quality and ecological health, a digital twin is a dynamic, virtual model of a real river system that combines real-time data from IoT sensors (on water quality, flow, and climate) with AI-powered models (34). This would enable policymakers to test the effects of a new discharge outlet on biodiversity or the release of reservoir water to clean a polluted area, for instance, virtually. In addition, the nationwide distribution of "Community eDNA Kits" may enable university students and local residents to become citizen scientists and add to a vast, dispersed database on aquatic biodiversity and pollution hotspots, raising awareness and facilitating the collection of detailed data (35).

### Mainstreaming and Financing for Sustainability

A significant change in agricultural subsidies is necessary to mainstream sustainable practices. Water-intensive crops and fertilizers should no longer be subsidized by the government; instead, "Regenerative Agricultural Practices" like cover crops, no-till farming, and agroforestry should be directly encouraged. These practices improve soil health, increase water infiltration, and significantly reduce chemical runoff, protecting farmland biodiversity and water quality (36). Pakistan must actively create a pipeline of "Blue-Green Bonds" designated for projects that provide co-benefits for ecosystem restoration (green) and water security (blue) in order to fund these ambitious projects. International ESG (Environmental, Social, and Governance) investment may be drawn to these certified bonds for initiatives such as the restoration of the Indus Delta mangroves, the development of urban wetlands, and the shift to regenerative agriculture (35).

### Biodiversity Protection and International Cooperation

Static protected areas must give way to dynamic "Climate-Resilient Ecological Corridors" in order to protect biodiversity. Pakistan can find and legally safeguard pathways that enable species to migrate and adapt to changing temperatures by using species distribution models under future climate scenarios. For endangered species like the Markhor and the Indus Dolphin, this is essential for preserving genetic flow between populations (37). Lastly, water diplomacy needs to be improved. Pakistan ought to advocate for the inclusion of "Transboundary Water Quality and Ecosystem Health" as a formal agenda item in the Permanent Indus Commission with India. It may be possible to create new opportunities for technical collaboration and collaborative funding for climate adaptation if it is framed as a shared challenge of maintaining the river basin's life-support system rather than merely a volumetric water-sharing issue (38).

# DISCUSSION

## Synthesis and Emerging Challenges

This review summarizes strong evidence that Pakistan's climate change is causing a serious crisis in biodiversity and water quality, not just water quantity. The connections are obvious: ecosystems suffer from degraded water, and ecosystems that are already compromised are less able to withstand climate shocks. Rapid urbanization, population growth, and the possibility of tipping points in important ecosystems like the Indus Delta are examples of emerging challenges.

## Research Gaps and Limitations

Pakistan's national monitoring systems continue to have significant research and data gaps, especially with regard to socio-ecological impacts, comprehensive biodiversity inventories, and real-time water quality parameters. This narrative review's dependence on previously published literature and policy documents may limit its ability to accurately depict localized, on-ground realities and all ongoing initiatives.

# CONCLUSION

The evidence is clear: Pakistan's biodiversity and water quality are being negatively impacted by climate change, resulting in a vicious cycle that jeopardizes human health, ecological integrity, and economic stability. Even though recent policy changes are encouraging, swift, coordinated, and enforced action is necessary for them to succeed. Irreversible losses will result from conducting business as usual. To guide Pakistan toward a resilient and sustainable future, a long-term vision supported by strong scientific research, sufficient funding, and unwavering political will at the national and international levels is essential.

# REFERENCES


1. Intergovernmental Panel on Climate Change (IPCC). (2023). Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In *Cambridge University Press*. Cambridge University Press. https://www.cambridge.org/core/product/identifier/9781009325844/type/book
2. Dayal, V., Duraiappah, A., & Nawn, N. (2018). *Ecology, Economy and Society*. Springer.
3. Archer, D. R., Forsythe, N., Fowler, H. J., & Shah, S. M. (2010). Sustainability of water resources management in the Indus basin under changing climatic and socio economic conditions. *Hydrology and Earth System Sciences*, *14*(8), 1669-1680. https://doi.org/10.5194/hess-14-1669-2010
4. Atta-ur-Rahman, & Khan, A. N. (2012). Analysis of 2010-flood causes, nature and magnitude in the Khyber Pakhtunkhwa, Pakistan. *Natural Hazards*, *66*(2), 887-904. https://doi.org/10.1007/s11069-012-0528-3
5. Chaudhry, Q. U. Z. (2017). Climate Change Profile of Pakistan. In *www.adb.org*. Asian Development Bank. https://www.adb.org/publications/climate-change-profile-pakistan
6. Buriro, T. Z., & Nisa Jatoi, Q. U. (2025). Pakistan's flood management strategies: A critical review of disaster preparedness, response, and risk mitigation. *Metallurgical and Materials Engineering*, *31*(4), 84-90. https://doi.org/10.63278/1409
7. Lutz, A. F., Immerzeel, W. W., Kraaijenbrink, P. D., Shrestha, A. B., & Bierkens, M. F. (2016). Climate change impacts on the upper Indus hydrology: Sources, shifts and extremes. *PLOS ONE*, *11*(11), e0165630. https://doi.org/10.1371/journal.pone.0165630
8. Immerzeel, W. W., Van Beek, L. P., & Bierkens, M. F. (2010). Climate change will affect the Asian water towers. *Science*, *328*(5984), 1382-1385. https://doi.org/10.1126/science.1183188
9. Mirza, M. M. (2010). Climate change, flooding in South Asia and implications. *Regional Environmental Change*, *11*(S1), 95-107. https://doi.org/10.1007/s10113-010-0184-7
10. Delpla, I., Jung, A., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. *Environment International*, *35*(8), 1225-1233. https://doi.org/10.1016/j.envint.2009.07.001
11. Azizullah, A., Khattak, M. N., Richter, P., & Häder, D. (2011). Water pollution in Pakistan and its impact on public health — A review. *Environment International*, *37*(2), 479-497. https://doi.org/10.1016/j.envint.2010.10.007
12. Azizullah, A., Khattak, M. N., Richter, P., & Häder, D. (2011). Water pollution in Pakistan and its impact on public health — A review. *Environment International*, *37*(2), 479-497. https://doi.org/10.1016/j.envint.2010.10.007
13. Levy, K., Woster, A. P., Goldstein, R. S., & Carlton, E. J. (2016). Untangling the impacts of climate change on Waterborne diseases: A systematic review of relationships between diarrheal diseases and temperature, rainfall, flooding, and drought. *Environmental Science & Technology*, *50*(10), 4905-4922. https://doi.org/10.1021/acs.est.5b06186
14. Dudgeon, D. (2019). Multiple threats imperil freshwater biodiversity in the Anthropocene. *Current Biology*, *29*(19), R960-R967. https://doi.org/10.1016/j.cub.2019.08.002
15. Schmitz, M., Flynn, D. F., Mwangi, P. N., Schmid, R., Scherer-Lorenzen, M., Weisser, W. W., & Schmid, B. (2013). Consistent effects of biodiversity on ecosystem functioning under varying density and evenness. *Folia Geobotanica*, *48*(3), 335-353. https://doi.org/10.1007/s12224-013-9177-x
16. Feinsinger, P., Rodríguez, I. V., Izquierdo, A. E., & Buzato, S. (2020). The inquiry cycle and applied inquiry cycle: Integrated frameworks for Field studies in the environmental sciences. *BioScience*, *70*(12), 1065-1081. https://doi.org/10.1093/biosci/biaa108
17. Breitburg, D. L., Baxter, J. W., Hatfield, C. A., Howarth, R. W., Jones, C. G., Lovett, G. M., & Wigand, C. (1998). Understanding effects of multiple stressors: Ideas and challenges. *Successes, Limitations, and Frontiers in Ecosystem Science*, 416-431. https://doi.org/10.1007/978-1-4612-1724-4_17
18. Braulik, G. T., Noureen, U., Arshad, M., & Reeves, R. R. (2015). Review of status, threats, and conservation management options for the endangered Indus River blind dolphin. *Biological Conservation*, *192*, 30-41. https://doi.org/10.1016/j.biocon.2015.09.008
19. Mangrio, A. M., Rafiq, M., Sheng, Z., Rind, N. A., Korejo, M. F., Naqvi, S. H., & Mangrio, S. M. (2020). Comparative study of growth and biochemical attributes of Avicennia marina (Forssk.) Vierh of Indus delta and in vitro raised plants established at Jamshoro, Sindh Pakistan. *Pakistan Journal of*

*Botany*, *53*(3). https://doi.org/10.30848/pjb2021-3(3)

20. Limnology and oceanography bulletin volume 32 number 2 May 2023 41-87. (2023). *Limnology and Oceanography Bulletin*, *32*(2), 41-87. https://doi.org/10.1002/lob.10578
21. Rabaiotti, D., Coulson, T., & Woodroffe, R. (2023). Climate change is predicted to cause population collapse in a cooperative breeder. *Global Change Biology*, *29*(21), 6002-6017. https://doi.org/10.1111/gcb.16890
22. McMullen, K., Calle, P., Alvarado-Cadena, O., Kowal, M. D., Espinoza, E., Domínguez, G. A., Tirapé, A., Vargas, F. H., Grant, E., Hunt, B. P., Pakhomov, E. A., & Alava, J. J. (2024). Ecotoxicological assessment of microplastics and cellulose particles in the Galapagos Islands and Galapagos penguin food web. *Environmental Toxicology and Chemistry*, *43*(6), 1442-1457. https://doi.org/10.1002/etc.5874
23. Ray, M., & Umapathy, G. (2022). Environmental DNA as a tool for biodiversity monitoring in aquatic ecosystems – a review. *Journal of Threatened Taxa*, *14*(5), 21102-21116. https://doi.org/10.11609/jott.7837.14.5.21102-21116
24. Wei, M., Wang, Y., & Giamporcaro, S. (2024). The impact of ownership structure on environmental information disclosure: Evidence from China. *Journal of Environmental Management*, *352*, 120100. https://doi.org/10.1016/j.jenvman.2024.120100
25. Ullah, W., Nihei, T., Nafees, M., Zaman, R., & Ali, M. (2017). Understanding climate change vulnerability, adaptation and risk perceptions at household level in Khyber Pakhtunkhwa, Pakistan. *International Journal of Climate Change Strategies and Management*, *10*(3), 359-378. https://doi.org/10.1108/ijccsm-02-2017-0038
26. Xu, F., & Chang, H. (2022). Soil greenhouse gas emissions and nitrogen change for wheat Field application of composted sewage sludge. *Agronomy*, *12*(8), 1946. https://doi.org/10.3390/agronomy12081946
27. Gardner, S. C., Neureuther, A., & Njoki, T. (2025). The UN decade on ecosystem restoration: The opportunity for tropical inland waters. *Progress on Ecosystem Restoration of Tropical Inland Waters*, 3-16. https://doi.org/10.1007/978-981-96-2284-9_1
28. Arfanuzzaman, M. (2025). Transboundary water cooperation and joint river basin management are pivotal for climate resilient development in South Asia. *World Development Perspectives*, *38*, 100681. https://doi.org/10.1016/j.wdp.2025.100681
29. Xu, F., & Chang, H. (2022). Soil greenhouse gas emissions and nitrogen change for wheat Field application of composted sewage sludge. *Agronomy*, *12*(8), 1946. https://doi.org/10.3390/agronomy12081946
30. Anwar, M., Rais, M., Baig, M. B., & Behnassi, M. (2022). Impacts of climate change on biodiversity in Pakistan: Current challenges and policy recommendations. *The Food Security, Biodiversity, and Climate Nexus*, 101-123. https://doi.org/10.1007/978-3-031-12586-7_6
31. Bank, A. D. (2020). Asian Water Development Outlook 2020: Advancing Water Security across Asia and the Pacific. In *www.adb.org*. Asian Development Bank. https://www.adb.org/publications/asian-water-development-outlook-2020
32. Malla, A., & Gautam, K. (2023). Handbook for on-grid rooftop solar PV design optimization. https://doi.org/10.53055/icimod.1025
33. Zheng, Y., Sun, G., Wei, S., Kong, L., Guo, J., Pan, W., Zhu, X., & Qi, X. (2025). Peroxisome proliferator-activated receptor pathway and key genes in cerebellar dysfunction induced by chronic intermittent alcohol exposure: A transcriptomic study. *Neurological Research*, 1-14. https://doi.org/10.1080/01616412.2025.2556244
34. Singh, D., & Sharma, V. (2025). Proposing a digital twin-based sustainable water governance system for rural Indian villages. *International Journal of Information Technology*, *17*(3), 1777-1783. https://doi.org/10.1007/s41870-025-02414-2
35. Grumbine, R. E., & Xu, J. (2021). Mountain futures: Pursuing innovative adaptations in coupled social–ecological systems. *Frontiers in Ecology and the Environment*, *19*(6), 342-348. https://doi.org/10.1002/fee.2345
36. Himshikha, Sharma, T., Kaur, T., Singh, A., Mohapatra, A., & Saikia, N. (2024). Regenerative agriculture and sustainable development goals. *Regenerative Agriculture for Sustainable Food Systems*, 135-174. https://doi.org/10.1007/978-981-97-6691-8_5
37. Stanley, A. E., Epanchin-Niell, R., Treakle, T., & Iacona, G. D. (2024). Attributes of preemptive conservation efforts for species precluded from listing under the U.S. Endangered Species Act. *Conservation Biology*, *38*(2). https://doi.org/10.1111/cobi.14200
38. Arfanuzzaman, M. (2025). Transboundary water cooperation and joint river basin management are pivotal for climate resilient development in South Asia. *World Development Perspectives*, *38*, 100681. https://doi.org/10.1016/j.wdp.2025.100681